E4-0101-TH(2)

(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) Publication number: **0 441 110 A1**

(12) **EUROPEAN PATENT APPLICATION**

(21) Application number: 90850404.6

(51) Int. Cl.[5]: **H03F 1/32**

(22) Date of filing: 13.12.90

(30) Priority: 22.01.90 SE 9000219

(43) Date of publication of application: **14.08.91 Bulletin 91/33**

(84) Designated Contracting States: **DE FR GB**

(71) Applicant: **TELEFONAKTIEBOLAGET L M ERICSSON**
S-126 25 Stockholm(SE)

(72) Inventor: **Ekelund, Björn Olof Peter**
Qvantenborgsvägen 10A
S-222 38 Lund(SE)
Inventor: **Jonsson, Lars Anders**
Dag Hammarskölds Väg 5C
S-223 64 Lund(SE)

(74) Representative: **Lövgren, Tage et al**
Telefonaktiebolaget L M Ericsson Patent Department
S-126 25 Stockholm(SE)

(54) **A method of compensating for non-linearities in an end amplifier incorporated in a radio transmitter.**

(57) A method of compensating for non-linearities in an end amplifier (F) having a given transfer function H_R, H_ϕ for amplitude and phase respectively and included in a radio transmitter of quadrature type for linear, digital modulation, and in which table look-up units (ST, CT) store the digital sine and cosine values ($I(t,\underline{\alpha})$, $Q(t,\underline{\alpha})$) of the quadrature components determined by a given signal vector $\underline{\alpha}$. According to the method the values of the transfer functions H_R, H_ϕ for the quadrature modulated radio signals $r(t,\underline{\alpha})$ are calculated by addressing memory units (MH1, MH2) which store a number of values of H_R and H_ϕ. The sine and cosine values of the addressed values of H_R and H_ϕ are also formed. The thus calculated values are multiplied by the stored digital values in the table look-up units (ST, CT) and by the inverted value of H_R. As a result, new modified values $i(t,\underline{\alpha})$, $q(t,\underline{\alpha})$ are obtained for the quadrature components, which compensates for the non-linearities in the final amplifier.

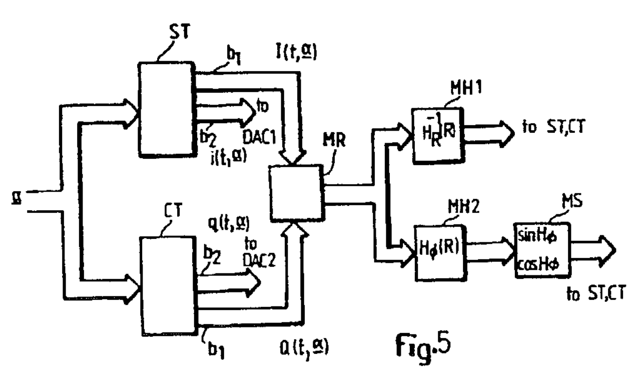

Fig.5

EP 0 441 110 A1

A METHOD OF COMPENSATING FOR NON-LINEARITIES IN AN END AMPLIFIER INCORPORATED IN A RADIO TRANSMITTER

TECHNICAL FIELD

The present invention relates to a method of compensating for those non-linearities that occur in an end amplifier forming part of a radio transmitter which operates with linear, digital quadrature modulation. A radio transmitter of this kind is used, for instance, within mobile telephony in the mobile telephone part, for transmitting digitized speech, data and control information to a base station.

BACKGROUND ART

The radio transmitter of the mobile telephone in mobile telephony has a compact and space saving construction. The signal information (data, speech, control signals) to be transmitted are modulated on a carrier wave having a given angular frequency w_c. The modulation method applied is so-called quadrature modulation, i.e. the carrier wave is divided into two quadrature components, sine w_ct and cos w_ct. These two components are then modulated with sine and cosine components of the information signal phase by, e.g., phase shift keying (QPSK). The information signal consists in a digital signal in the form of a bit flow of "ones" and "zeros". In the case of QPSK, a binary "one" corresponds to a given positive phase change or shift and a "zero" corresponds to a negative phase change or shift in the transmitted radio signal. The phase changes always start from the phase position of the preceding bit, so that subsequent to filtration the phase of the transmitted radio signal will have continuous progress in the absence of abrupt changes.

In order to form the radio signal r(t) to be transmitted, it is therefore necessary to form the sine and cosine values of a given phase angle (= phase change), these values being projected onto the two carrier wave components in the modulation process. These two values are called quadrature components and are normally designated I and Q respectively. It is known to use waveform generators which comprise memory stores in which these components are formed for a given phase change. For instance, US Patent Specification 4,229,821 describes a waveform generator which contains two table look-up memories for each sine ϕ and cos ϕ. These two memories are addressed by a signal vector $\underline{\alpha}$ with a given number of bits depending on the duration of the low-pass-filter impulse response (the impulse response of the premodulation filters) included in the tables. The duration of the impulse response is normally truncated to a given number of bits, this number depending on the required quality of the transmitted radio signal.

Downstream of the modulator circuits in the transmitter is a final amplifier which operates in amplifying the radio signal $r(t,\underline{\alpha})$ to a given power for transmission from the transmitter antenna of the mobile telephone. Since the quadrature modulation applied is linear, i.e. the transmitted information influences both the amplitude and phase position of the radio signal, the amplification of the final amplifier must also be linear both with respect to amplitude and phase position.

DISCLOSURE OF THE INVENTION

The final stage of the transmitter, which normally consists of the end amplifier, operates in class C, i.e. its transistor circuits are biased so as to be located beneath the cut-off of the collector current when at rest. This means, however, that the quadrature components of an incoming signal will be distorted, because the amplifier does not operate within its linear range. Consequently, it is necessary to weigh the advantage of having the amplifier working within the class C region (high electric efficiency) against this disadvantage. The present invention utilizes the fact that the waveform generator includes the aforesaid table units for forming the quadrature components, i.e. the signal which is later to be amplified. It is possible to compensate for the non-linearity of the final amplifier, by modifying the digital values stored in the table units.

The inventive method is therewith characterized by the features set forth in the characterizing clause of the following Claim 1.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be described in more detail with reference to the accompanying drawings.

Figure 1 is a block diagram of a theoretic model of a radio transmitter for digital modulation;

Figure 2 is a block diagram of a known type of waveform generator in a radio transmitter and in which the proposed invention is applied;

Figure 3 is a diagram which illustrates the quadrature components of the phase position of a radio signal;

Figures 4a-4c illustrate the various positions of the quadrature components in a radio signal which varies in time;

Figure 5 is a block diagram of a hardware solution according to the proposed method;

Figure 6 is a block diagram illustrating another type of waveform generator to that shown in Figure 3, where the proposed method can be applied.

Figure 1 is a simplified block diagram of a quadrature modulator. An incoming signal is applied to an NRZ-converter 1, so as to form a binary coded signal. A premodulation filter 2 of lowpass character produces an impulse response of given length, which is determined by the number of transmitted symbols which are to be stored in the subsequent quadrature modulator 3 at each moment in time. The modulator 3 is described below with reference to Figures 3 and 4. A final stage 4 is connected to the output of the quadrature modulator and to the input of the transmitted antenna 5, so as to give the radio signal sufficient power upstream of the antenna.

The modulator 3 is a so-called QPSK-modulator and utilizes the division of the signal into quadrature components. These components consist of the projections of the radio signal on two versions of an imaginary carrier wave sine $w_c t$ and cos $w_c t$ phase-shifted through 90°, where w_c is the carrier angle frequency. The quadrature components or the quadrature signals have a lowpass character and constitute baseband signals.

In theory, QPSK has an infinite bandwidth. In practical applications, the modulation is always complemented with some form of prefiltration with the aid of the premodulation filter 2 illustrated in Figure 1.

The traditional method of generating a QPSK-signal prior to dividing the signal into quadrature signals with subsequent modulation, is to apply the binary signals to an array of digital flip-flops and analogue filters. Figure 3 illustrates a QPSK-generator with table look-up and a shift register whose length is equal to the number of bits (= two) used for QPSK. The shift register comprises a number of flip-flops D1-D7 equal to the number of symbols which are to be stored with respect to the impulse response of the premodulation filter. In the present case, each symbol consists of two bits and the number of symbols is equal to eight. The impulse response of the premodulation filter is thus truncated to a length which corresponds, in the present case, to the duration of eight symbols. The length of the impulse response is determined by the quality requirements placed on the generated radio signal. The shift register is terminated with an up-down counter QM which memorizes the output point of the waveforms of the symbol stored at that moment. This is necessary because the information is transferred by means of state transitions instead of absolute positions in the I-Q plane. Thus, during one symbol interval Ts the shift register D1-D8 and the memory counter QM store a signal vector $\underline{\alpha}$ which consists of the symbol concerned and its nearest neighbour, and a value (in the counter QM) which denotes the starting point of the phase position.

Figure 3 is a rotating vector diagram of an arbitrary radio signal $r(t,\underline{\alpha})$ which is to be transmitted with an absolute magnitude (amplitude) $R(t,\underline{\alpha})$ and a phase angle $\phi(t,\underline{\alpha})$. The radio signal is divided into two quadrature components $I(t,\underline{\alpha})$ and $Q(t,\underline{\alpha})$, which constitute "the projections" of the two carrierwave components cos $w_c t$ and sine $w_c t$ respectively of the carrierwave components and phase displaced through 90°. The quadrature components $I(t,\underline{\alpha})$ and $Q(t,\underline{\alpha})$ are stored in the table units ST and CT respectively in the modulator shown in Figure 2, for all possible signal vectors $\underline{\alpha}$. The following relationship applies for the radio signal $r(t,\underline{\alpha})$:

$r(t,\underline{\alpha}) = R(t,\underline{\alpha}) \cdot \cos[w_c t + \phi(t,\underline{\alpha})]$

where

$$R(t,\underline{\alpha}2) = \sqrt{I^2(t,\underline{\alpha}) + Q^2(t,\underline{\alpha})}$$

and

$\phi(t,\underline{\alpha}) = \arg[I(t,\underline{\alpha}) + j\,Q(t,\underline{\alpha})]$

Figures 4a-4c illustrate three different radiosignals ($r(t,\underline{\alpha})$ corresponding to three different signal vectors α_1, α_2 and α_3, which are delivered from the shift register D1-D8 and the counter QM. Each of the signal vectors indicates the two quadrature components $I(t,\underline{\alpha})$ in the table units ST and CT. These components are stored respectively as a sine and cosine waveform in the table units. The waveform samples are brought

forward in sequence with the aid of the counter SR, and the thus obtained digital values are applied to the digital-analogue converters DAC1, DAC2. The signals are then low-pass filtered in the filters FR1, FR2 prior to modulation of the carrier waveform components in the multipliers M1, M2 and addition in the summing circuit ADD.

If the impulse response h_T of the premodulation filter is truncated to a given length $N_I \cdot T_S$, where N_I is an integer and T_S is the symbol time, and if the truncated impulse response has its centre at t = 0 and a propagation from $-T_S N_I/2$ to $+T_S N_I/2$, the following expression is obtained for the quadrature components:

$$I(kT_s + t, \underline{\alpha}) = \sum_{i=0}^{N_I - 1} h_T\left(t + T_s \cdot \left[\frac{N_I}{2} 1 - i\right]\right) \cdot \cos\left(\frac{2\pi}{N} \cdot \alpha(i+k)\right)$$

$$Q(kT_s + t, \underline{\alpha}) = \sum_{i=0}^{N_I - 1} h_T\left(t + T_s \cdot \left[\frac{N_I}{2} 1 - i\right]\right) \cdot \sin\left(\frac{2\pi}{N} \cdot \alpha(i+k)\right)$$

It will be evident from the above formulae that $I(t,\underline{\alpha})$ and $Q(t,\underline{\alpha})$ are stored as cosine and sine waveforms respectively in respective table units ST and CT.

The aforedescribed modulation method is linear, i.e. the relationship between incoming signal vectors $\underline{\alpha}$ and the output signals $I(t,\underline{\alpha})$ and $Q(t,\underline{\alpha})$ present a number of linear properties. This means, however, that the units included in the transmitter downstream of the table units must also be linear, in order to ensure that the relationship between incoming signal vectors and output signals will also be maintained, and thereby avoid impairing quality and disturbing other subscribers. The problem of obtaining a linear end amplifier F (Figure 2) can occur in particular. The method proposed in accordance with the invention ignores the problem of linearizing the end amplifier and instead endeavours to compensate for this non-linearity in the table units ST and CT.

If the transmission function of the end amplifier is H_R and H_ϕ for the input signal amplitude R_1 and its phase angle ϕ_1, the following applies with respect to the output signal:

$R_2 = H_R(R_1) \cdot R_1$
$\phi_2 - H_\phi(R1) + \phi_1$

The inverse of H_R and H_ϕ can be written as:

$R_1 = H^{-1}{}_R (R_2) \cdot R_2$ and
$\phi_1 = H_\phi^{-1} (R_2) + \phi_2$ where
$H_R^{-1} = 1/H_R$ and $H_\phi^{-1} = H_\phi$

The inverse transfer functions H_R^{-1} and H_ϕ^{-1} can be calculated by measuring a number of output signals R_2 for a given number of input signals R_1 and constitute static time-independent functions.

In order to obtain a correct output signal from the distorted end amplifier F, it is necessary to modify the contents of the look-up tables ST and CT according to Figure 3 with H_R^{-1} and H_ϕ^{-1}. This is effected mathematically in accordance with the following relationship:

$i(t,\underline{\alpha}) = H_R^{-1}(R) \left[I(t,\underline{\alpha}) \cdot \cos H_\phi(R) - Q(t,\underline{\alpha}) \cdot \sin H_\phi(R)\right]$

$q(t,\underline{\alpha}) = H_R^{-1}(R)[I(t,\underline{\alpha}) \sin H_\phi(R) + Q(t,\underline{\alpha}) \cos H_\phi(R)]$ (1)

where $i(t,\underline{\alpha})$, $g(t,\underline{\alpha})$ are the modified waveform values which are intended to replace the original values $I(t,\underline{\alpha})$, $Q(t,\underline{\alpha})$.

Since H_R and H_ϕ are statically time-independent functions, these functions can be stored in the tables ST and CT for the transfer function of a given final amplifier.

According to the aforegoing, the value of R of a given signal vector $\underline{\alpha}$ can be calculated from the relationship:

$$R = \sqrt{I^2(t,\underline{\alpha}) + Q^2(t,\underline{\alpha})} \qquad (2)$$

since $I(t,\underline{\alpha})$ and $Q(t,\underline{\alpha})$ for the signal vector is stored in respective table units ST, CT. Thus, when R is known, H_R and H_ϕ and therewith also H_R^{-1} and H_ϕ^{-1} can be calculated. This enables the new coefficients in $(t,\underline{\alpha})$ and $q(t,\underline{\alpha})$ for the signal vector $\underline{\alpha}$ to be calculated from the relationship (1) above.

Thus, in the case of a given signal vector $\underline{\alpha}_k$ whose waveforms are to be calculated, the various steps in modifying the content $I(t,\underline{\alpha})$ and $Q(t,\underline{\alpha})$ in respective table units ST and CT will be as follows:

1. Calculation of the amplitude R from the non-modified values $I(t,\underline{\alpha})$, $Q(t,\underline{\alpha})$ for the signal vector $\underline{\alpha}_k$ according to relationship (2) above.
2. Calculation of the value of the transfer functions $H_R(R)$ and $H_\phi(R)$ for the value of R calculated according to step 1. The transfer functions $H_R(R)$ and $H_\phi(R)$ are calculated from measuring data and stored in respective units ST and CT.
3. Calculation of the new modified values $i(t,\underline{\alpha}_k)$ and $q(t,\underline{\alpha}_k)$ from the relationship (1) above. The new values are stored during the whole of the sampling interval $0 \leq < T_S$.
4. Sampling of the new values $i(t,\underline{\alpha}_k)$, $q(t,\underline{\alpha}_k)$ at the sampling time points t_1, t_2, ... in a known manner during the symbol interval $0 \leq t < T_S$.
5. Transmission of the sampled digital values to the digital-analogue converters DAC1, DAC2 and further to remaining units according to Figure 2.
6. New signal vectors $\underline{\alpha}_{k+1}$ occur over the inputs to the table units ST, CT from the registers D1-D8 and the quadrante memory QM, steps 1-5 above being repeated.

Figure 5 is a simplified block diagram which illustrates those memory and arithmetical units which effect modification of the quadrature components $I(t,\underline{\alpha})$, $Q(t,\underline{\alpha})$ stored in the table units ST and CT.

The non-modified (original) values of $I(t,\underline{\alpha})$ and $Q(t,\underline{\alpha})$ are obtained from an outgoing bus b_1 at a given sampling time point $t=t_1$. These values are delivered to a calculating unit MR which calculates the value

$$|r(t_1,\underline{\alpha})| = \sqrt{I(t_1,\underline{\alpha})^2 + Q(t_1,\underline{\alpha})^2} = R(t_1,\underline{\alpha}).$$

This calculated value $R(t_1,\underline{\alpha})$ is caused to address two memory units MH1 and MH2. The memory unit MH1 stores a quantity of inverted values of the amplifying factor $H_R(R)$, i.e. $H_R^{-1}(R)$ for different input signals R to the end amplifier F. The values $H_R(R)$ can be obtained by carrying out measurements on the amplifier F and, according to the aforegoing, constitute a static, time-independent function of R. The memory unit MH2 stores corresponding values $H_\phi(R)$ of the phase characteristic of the end amplifier F, which similar to $H_R(R)$ is static and time-independent. The memories MH1, MH2 thus constitute static adressable ROM:s.

The addressed value of $H_\phi(R)$ in the memory unit MH2 is applied to a table unit MS which calculates sine $H_\phi(R)$ and cos $H_\phi(R)$. These two values are transferred to the table units ST and CT and are multiplied by the non-modified values $I(t_1,\underline{\alpha})$, $Q(t_1,\underline{\alpha})$ according to relationship (1) above. The value of $H_R^{-1}(R)$ is delivered to the memory unit MH1 at the same time and is multiplied by $I(t_1,\underline{\alpha})$, $Q(t_1,\underline{\alpha})$ according to (1).

When the next sampling takes place at $t=t_2$ (but for the same symbol vector $\underline{\alpha}$) the unit MR is again addressed and calculates the modified values $i(t,\underline{\alpha})$, $q(t,\underline{\alpha})$, for $t=t_2$ in the manner described above. The values $i(t_1,\underline{\alpha})$, $q(t_1,\underline{\alpha})$ are, at the same time, delivered to the digital-analogue converters DAC1, DAC2 over the busses b_2.

The above method for compensating non-linearities can also be applied with a quadrature modulator of the configuration illustrated in Figure 6. In this embodiment, the waveform generator tables have been divided into several part tables: One I-table and one Q-table of simplified form and two mutually identical waveform tables SV and CV. In this embodiment the coefficients in the tables ST and CT are modified in

accordance with the method above described.

Claims

1. A method of compensating for non-linearities in an end amplifier (F) with a transfer function H_R, H_ϕ for the amplitude and phase respectively of an incoming radio signal, and included in a radio transmitter of quadrature type for linear, digital modulation based on table look-up and analogue-digital conversion containing register means (BHR, QM) which function to store binary values of a momentary phase angle and an accumulated phase angle of an information signal to the radio transmitter, so as together to form a signal vector $\bar{\alpha}$ of given length which depends on the length of the impulse response h(t) of a premodulation filter of the radio transmitter; storage means (ST, CT) which function to store the digital values of sine and cosine waveform $(I(t,\bar{\alpha}), Q(t,\bar{\alpha}))$ belonging to those quadrature components which are addressed by means of said signal vector $\bar{\alpha}$ projected on two carrierwave components (sine w_ct, cos w_ct); and further containing multiplier and addition means (M1, M2; ADD) which form a quadrature-modulated radio signal $r(t,\bar{\alpha})$ from said carrierwave components and said quadrature components, **characterized** in that the digital values $I(t,\bar{\alpha})$, $Q(t,\bar{\alpha})$ stored for the different waveforms in said storage means (ST, CT) are modified in dependence on said transfer functions H_R and H_ϕ of the final amplifier (F) so that new digital values $i(t,\bar{\alpha})$, $q(t,\bar{\alpha})$ are obtained for said waveforms which, upon quadrature modulation, compensate the radio signal for said non-linearities.

2. A method according to Claim 1, **characterized** by forming from the original digital values $I(t,\bar{\alpha})$, $Q(t,\bar{\alpha})$ a value $R(t,\bar{\alpha})$ which gives the absolute value $|r(t,\bar{\alpha})|$ of the quadrature-modulated radio signal; adressably storing a plurality of digital values of the transmission functions H_R and H_ϕ of the end amplifier (F); addressing a given value of said transmission functions H_R and H_ϕ by said calculated value of $R(t,\bar{\alpha})$, therewith to obtain a first value $H_R(R)$ of the amplitude-dependency of the end amplifier and a second value $H_\phi(R)$ of the phase-dependency of the amplifier; and multiplying said first value $H_R(R)$ and sine-cosine components of said second value $H_\phi(R)$ by the original digital values $I(t,\bar{\alpha})$ and $Q(t,\bar{\alpha})$ in a manner such that the new modified digital values $i(t,\bar{\alpha})$ and $q(t,\bar{\alpha})$ obtained in said storage means (ST, CT) have an absolute value which is equal to the absolute value of the original digital values multiplied by a factor $1/H_R(R)$.

3. A method according to Claim 2, **characterized** by obtaining the new modified digital values $i(t,\bar{\alpha})$, $q(t,\bar{\alpha})$ of the waveforms from the relationships: $i(t,\bar{\alpha}) = H_R^{-1}(R)\,[I(t,\bar{\alpha}) \cos H_\phi(R) - Q(t,\bar{\alpha}) \text{ sine } H_\phi(R)]$ $q(t,\bar{\alpha}) = H_R^{-1}(R)\,[I(t,\bar{\alpha}) \text{ sine } H_\phi(R) + Q(t,\bar{\alpha}) \cos H_\phi(R)]$ where $H_R(R)$ and H_ϕ (R) are said addressed values of the amplitude-dependency and phase-dependency respectively of the final amplifier (F).

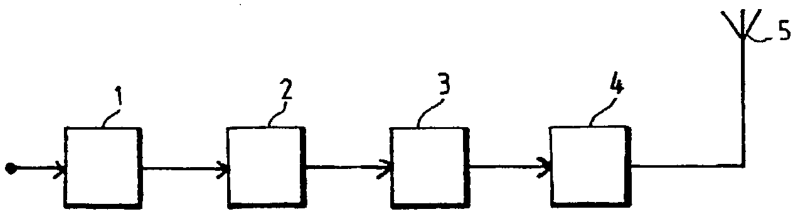
1
2
3
4
5

Fig.1

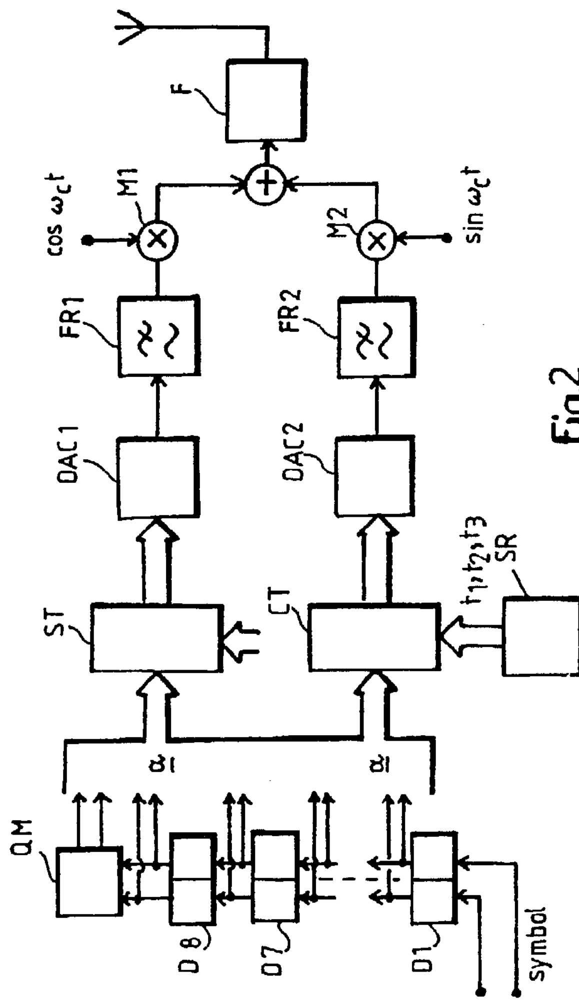
F
M1
M2
cos $\omega_c t$
sin $\omega_c t$
FR1
FR2
DAC1
DAC2
ST
CT
t_1, t_2, t_3
SR
QM
D8
D7
D1
symbol

Fig.2

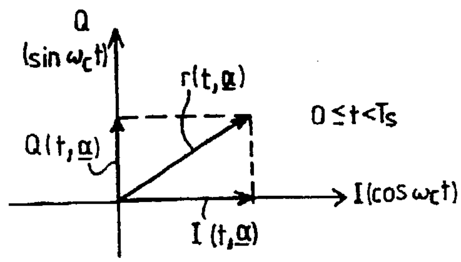

Fig.3

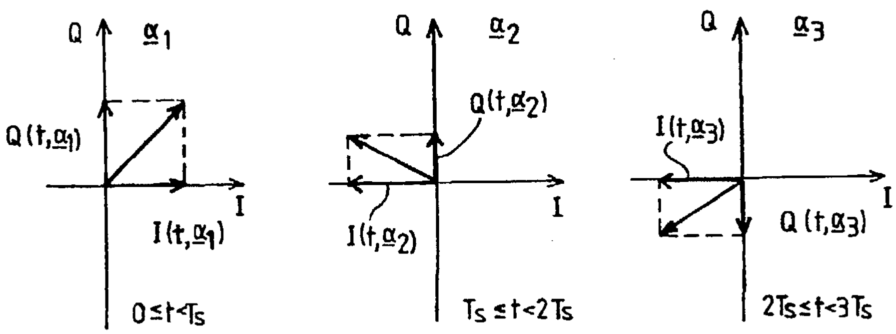

Fig.4a Fig.4b Fig.4c

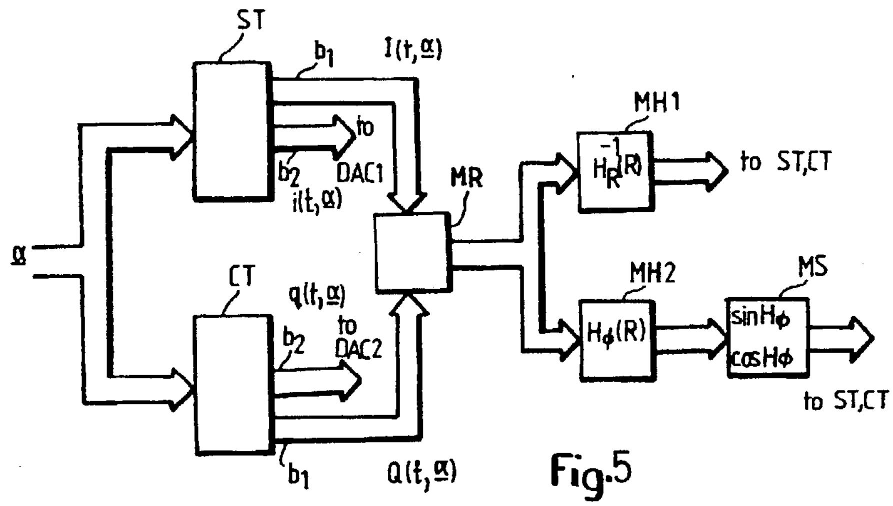
ST
b_1
$I(t,\underline{\alpha})$
MH1
to
b_2
DAC1
$i(t,\underline{\alpha})$
MR
$H_R^{-1}(R)$
to ST,CT
$\underline{\alpha}$
CT
$q(t,\underline{\alpha})$
MH2
MS
b_2
to
DAC2
$H_\phi(R)$
$\sin H_\phi$
$\cos H_\phi$
to ST,CT
b_1
$Q(t,\underline{\alpha})$

Fig.5

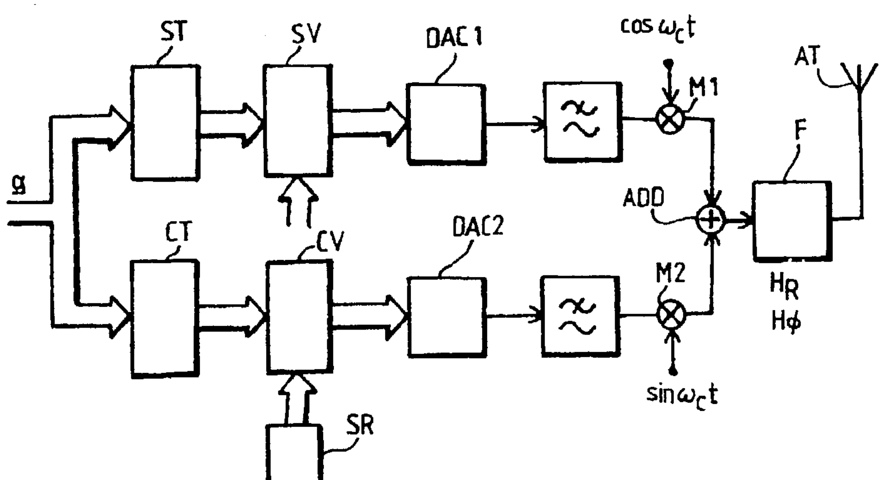
ST
SV
DAC 1
$\cos \omega_c t$
AT
M1
F
$\underline{\alpha}$
ADD
CT
CV
DAC2
M2
H_R
H_ϕ
$\sin\omega_c t$
SR

Fig.6

European Patent Office

EUROPEAN SEARCH REPORT

Application number

EP 90850404.6

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int Cl⁵)
A	US-A- 4 229 821 (DE JAGER ET AL) *figure 1* ---	1-3	H 03 F 1/32
A	GB-A- 2 073 516 (N.V. PHILIPS GLOE-ILAMPENFABRIKEKEN) *figure 2a* ---	1-3	
A	DE-A- 2 304 352 (WESTERN ELECTRIC CO INC) *claim 1* ---	1-3	
A	FR-A1-2 469 826 (LECOY) *claim 1 --- --------	1-3	

TECHNICAL FIELDS SEARCHED (Int Cl⁵)

H 03 F
H 04 B

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
STOCKHOLM	30-04-1991	LJUNGDAHL B.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO Form 1503 03 82